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6. AUTHOR(S)
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7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
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13. ABSTRACT *(Maximum 200 words)*

We summarize our sixth quarter progress towards developing a thin-film-edge emitter vacuum transistor capable of 1 GHz modulation for sustained (>1 hour) periods of time. We completed extensive DC characterization of completed devices. We also performed low frequency modulation tests of the vacuum transistors at 10-100 KHz. We designed a vacuum feedthrough with high frequency probes for testing vacuum transistors at 2-4 GHz (BNC connectors) and 10-12 GHz (SMA connectors). A program review was held at the conclusion of the baseline phase. We also replanned the option phase of the program with a goal of obtaining vacuum transistors that have 1 GHz modulation with gain.

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R&D Status Report
RF Vacuum Microelectronics
Quarterly Progress Report #6
(1/1/93 - 3/31/93)

Sponsored by:

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ARPA/DSO
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Arlington, Virginia 22203
Tel: 703/696-2239

Contractor: Honeywell Sensor and System Development Center
10701 Lyndale Avenue South
Bloomington, MN 55420

Effective Date of Contract: September 30, 1991

Contract Expiration Date: March 31, 1993 (Baseline)

Contract Amount: Baseline	$1,315,650
Option:	$ 772,532

Principal Investigator:	Tayo Akinwande 612/887-4481
Program Manager:	David K. Arch 612/887-4404

Title of Work: **RF Vacuum Microelectronics**

I. Executive Summary

Technical Approach: Our technical approach is to utilize thin film technology and surface micromachining techniques to demonstrate an edge emitter based vacuum triode. The edge emitter triode approach offers several potential advantages to achieving high frequency device operation (compared to cone emitters or wedge emitters):

- The fabrication process is a planar process, compatible with most silicon IC manufacturing.
- Thin film processes for the films used in the triode process are well controlled and reproducible. Control of film thicknesses to within 5% for the emitter film thickness is easily attainable resulting in a well-controlled edge emitter.
- Device capacitance for the edge emitter is less than that achievable for cones or wedges resulting in potentially higher frequency operation.

Program Objective: Demonstrate an edge emitter based vacuum triode with emission current density of 10 μA/μm at less than 250 V which can be modulated at 1 GHz continuously for 1 hour.

Key Achievements (this reporting period)

- Demonstrated low frequency (10-100 KHz) modulation of a thin-film-edge emitter vacuum transistor.
- A review of the VME program was held with the VME technical committee on February 1, 1993.

II. Milestone Status

	Completion Date Planned	Actual (estimate)
1. Field Emitter Development		
Test Structure Design Complete	12/91	1/92 (complete)
Determine Workable Emitter Structure	3/92	3/92 (complete)
Demonstrate Emission Current of 10 μA/μm	11/92	11/92 complete
Deliver 10 Field Emitting Diodes	12/92	12/92 (on plan) (delivered 10/13/92)
2. Process Development		
High Resistivity Thin Film Resistor	4/92	9/92 (complete)
Complete Dielectric Studies	5/92	6/92 (complete)
Mechanical and Electrical FEM Analysis	5/92	8/92 (complete)
3. Triode Development		
-Triode Design Complete	4/92	5/92 (complete)
-Demonstrate Reliable/Uniform Current Emission	7/92	10/92 (complete)
-Demonstrate Modulated/Edge Emitter Triode	8/92	12/92 (complete)
-Demonstrate 1 GHz Modulation of Triode	2/93	12/92 (behind plan)
-Deliver 2 Triodes	3/93	2/93 (on plan)
4. Final Report (Baseline)	4/93	4/93 (on plan)

III. Technical Progress

Efforts during this reporting period focussed on fabrication and testing of the thin film edge emitter vacuum transistors.

Task 1. Field Emitter Development

This task was completed at the end of the fourth quarter.

Task 2 Process Development

This task was completed at the end of the fourth quarter.

Task 3 Triode Development

Our efforts in the quarter focused on:

- DC characterization of the vacuum transistor.
- Low frequency modulation test of the vacuum transistor.
- Development of a vacuum feedthrough with high frequency probes for microwave measurements.
- Development of processes for obtaining higher yields during the fabrication of vacuum transistor arrays.

DC Characterization

Table 1 summarizes the DC characterization results for the vacuum transistor showing that the vacuum transistor can attain 1 GHz operation with gain. Our results indicate the expected triode action with both gate and anode (collector) voltages determining the emitter and anode currents as shown in Figure 1. We also observed that greater than 95% of the emitter current is collected by the anode.

Modulation Tests

We performed modulation test and characterization of the edge-emitter and vacuum transistor. Figures 2 to 7 show the modulation test of a vacuum transistor at 10 kHz. The top trace in all cases are the outputs while the bottom trace is the input. The figures indicate that the output signal increases as the gate voltage (and anode current) increases. However, we were not able to test the devices beyond 100 kHz for the following two major reasons:

- There is a severe impedance mismatch between the output impedance and the impedance of the test equipment. This resulted in signal attenuation of >75 dB.
- There is significant feedthrough between the input and the output of the vacuum probe because the BNC connectors are not isolated. The feedthrough isolation between input and output is only about 60 dB.

Vacuum Feedthroughs with High Frequency Probes

As a result of our modulation tests and analysis of our high frequency test approach we concluded that we needed a new approach for coupling high frequency signals to the device if we are going to characterize the devices on-wafer. The most important issue is the reduction of the feedthrough. Our new technical approach is to use floating shield connectors in the vacuum feedthroughs. This will allow us to have only one ground connection at the emitter of the device. The vacuum flange will have BNC or SMA connectors whose shields are not grounded to the body of the flange. The connectors are fed by rigid coaxial cables to the device probes. The device probes are mounted on 50 Ω printed circuit board with a ground plane. The ground plane is connected to the emitter probe and the shields of the gate (input) and anode (output) probes.

We have ordered the vacuum flange with BNC connectors and it should be delivered in early May. We plan to order the vacuum flanger with SMA connectors in early May.

Process Development

Under Honeywell funding we carried out process development to improve the fabrication yield of the vacuum transistor array. As we concluded above, there is a severe impedance mismatch between the vacuum transistor and the test equipment leading to very inefficient power transfer. As planned for the option phase, we can build devices with higher currents by using wider edges. Our goal is to attain currents of 1-10 mA using edges that are 1000 μm long. We developed processes that will improve the fabrication yield for these long edges by using non-contact photolithography.

Table 1.

Vacuum Microelectronics Program

Thin Film Edge Emitter
Vacuum Transistor

SUMMARY OF DEVICE PARAMETERS DEMONSTRATED

Device Parameter	Measured Value
Device Width	4 μm
Turn-on Voltage (0.1 μA)	50 Volts
Max Current	50 μA
Current Density	12.5 μA / μm
Extrinsic Transconductance (including 1 MΩ resistor)	0.6 μS / μm
Intrinsic Transconductance (excluding Resistor)	1.5 μS / μm
Capacitance [2.5 μm gate length] (measured)	0.3 fFarad/μm
ft (calculated)	1.06 GHz
Emission Time (measured)	1 hour

Vacuum Transistor Transfer Characteristics I

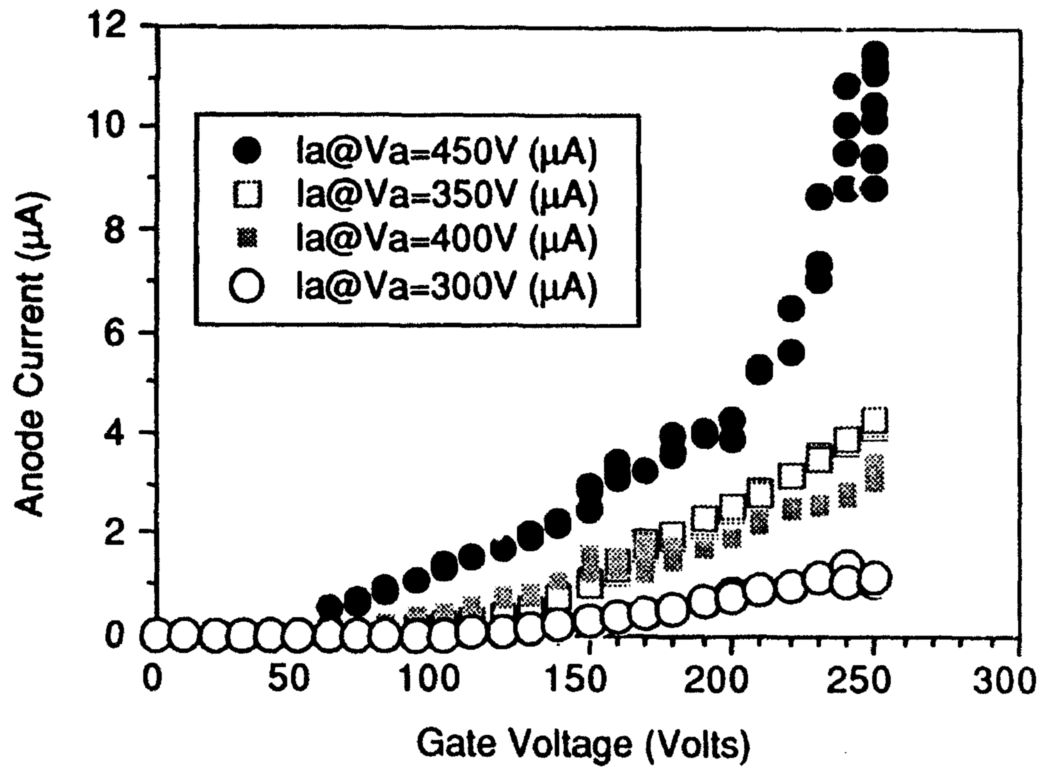


Figure 1.

Sensor and System Development Center
Honeywell Inc.
10710 Lyndale Avenue South
Bloomington, MN 55420
(612) 887-4317

Triode Modulation
Mask: 5313
Wafer: P1
Device: TR6
Frequency: 10 KHz

Anode @ 300 volts
Control @ 0 volts

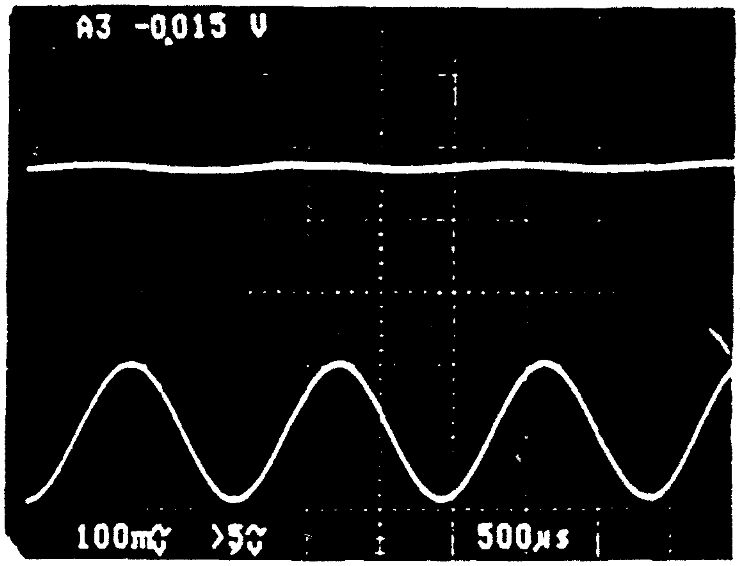


Figure 2.

Anode @ 300 volts
Control @ 60 volts

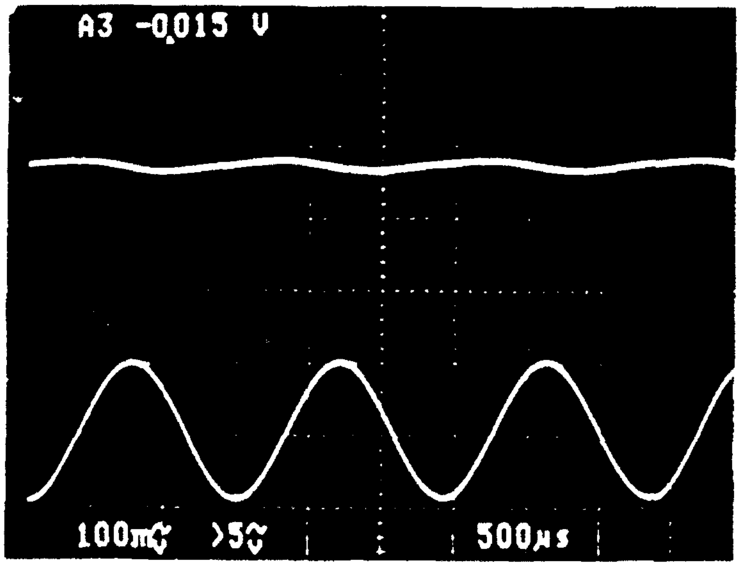


Figure 3.

Sensor and System Development Center
Honeywell Inc.
10710 Lyndale Avenue South
Bloomington, MN 55420
(612) 887-4317

Triode Modulation
Mask: 5313
Wafer: P1
Device: TR6
Frequency: 10 KHz

Anode @ 300 volts
Control @ 80 volts

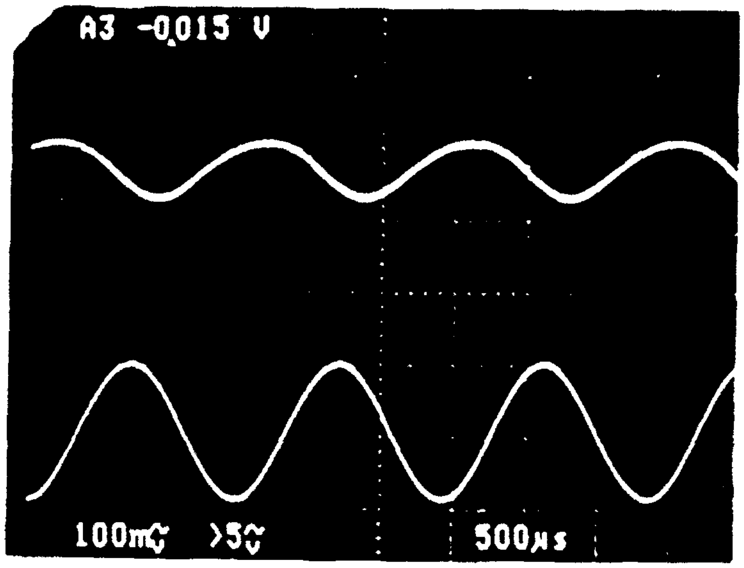


Figure 4.

Anode @ 300 volts
Control @ 100 volts

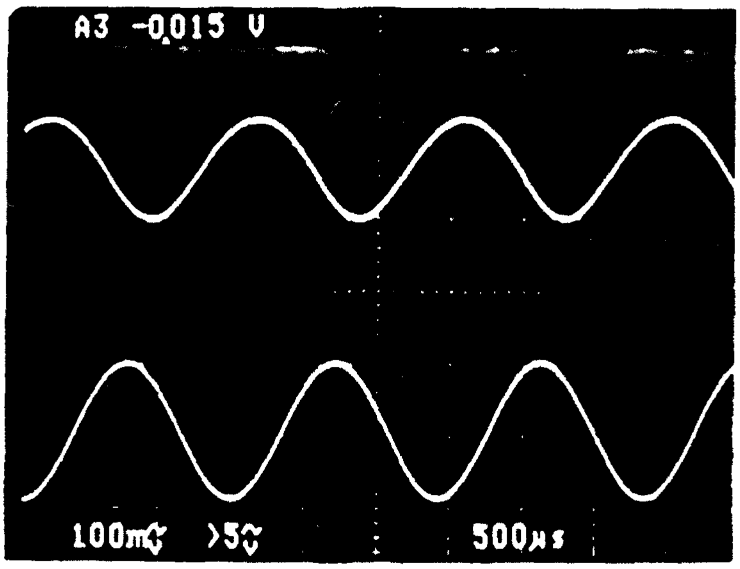


Figure 5.

Sensor and System Development Center
Honeywell Inc.
10710 Lyndale Avenue South
Bloomington, MN 55420
(612) 887-4317

Triode Modulation
Mask: 5313
Wafer: P1
Device: TR6
Frequency: 10 KHz

Anode @ 300 volts
Control @ 120 volts

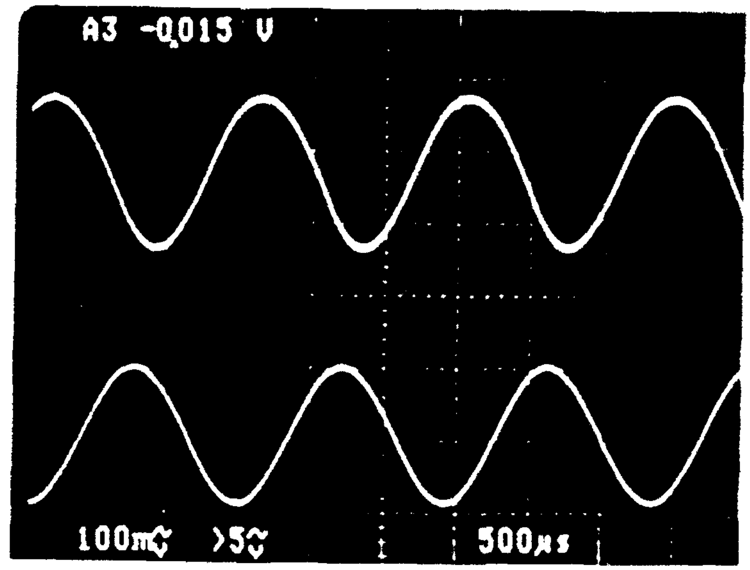


Figure 6.

Anode @ 300 volts
Control @ 140 volts

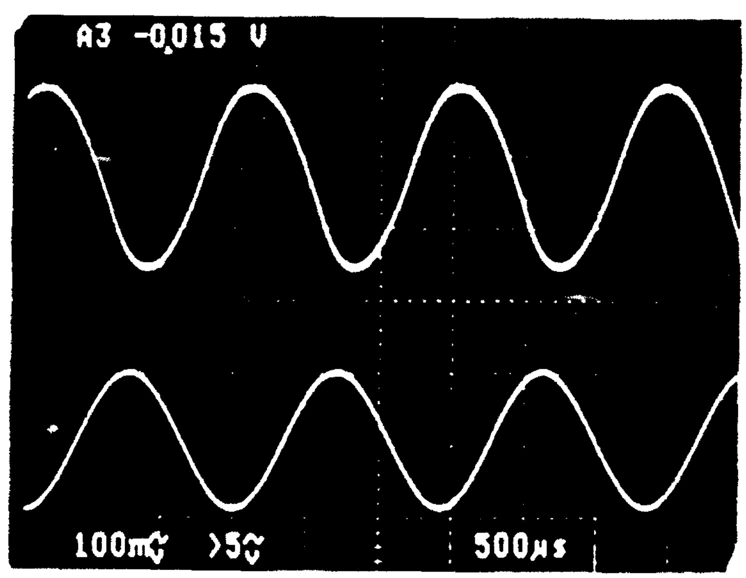
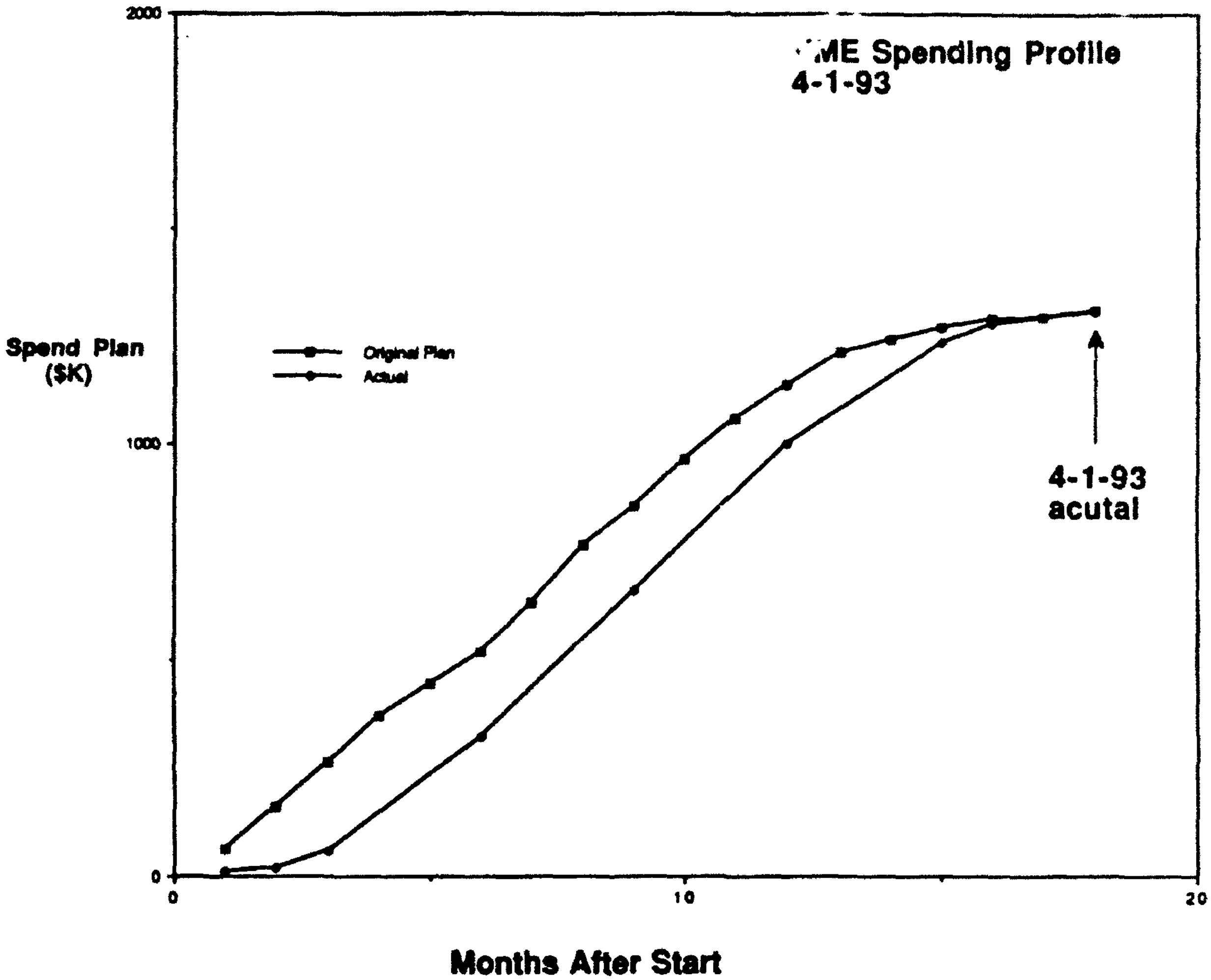


Figure 7.

IV. Fiscal Status



Expenditures this quarter	$ 73K
Total expenditures to date	$1,308K
Projected expenditures (baseline):	
4/93 - 6/93	$ 5K

Total Projected Cost for Baseline Program $1,315,650*

*Total cost to ARPA. Total projected cost of the baseline program is $1390K. The remaining funding ($75K) is being cost shared by Honeywell through a limitation of its overhead rates. In addition, as a result of the February 1, 1993 program review with ARPA, Honeywell agreed to an additional investment (internal development funds) of approximately $71K to provide further testing, testing enhancements and process enhancements to the VME effort. Of this $71K committed, approximately $61K has been spent to date.

Plans for Next Reporting Period

The option phase of the program has been restructured. The new objective is to demonstrate a 1 GHz thin-film-edge emitter vacuum transistor with gain. This seven-month program will begin May 1, 1993. During this next quarter we will:

- Design the vacuum transistor array to achieve the objective above.

- Begin fabrication of the transistor array.

- Complete the installation and characterization of the high frequency vacuum feedthroughs/probes.

V. Programmatics

- A review of the Honeywell VME program with the ARPA VME committee was held at SSDC on February 1, 1993. Valuable feedback was given to Honeywell by the committee concerning technical focus and direction. As a result of this meeting, Honeywell SSDC committed approximately $71K of its resources to further test VME devices and improve its high frequency vacuum testing capability.

- At the request of Dr. Bertram Hui, SSDC submitted a proposal to complete the demonstration of 1 GHz modulation with the thin film edge emitter triode. A seven-month program was proposed which calls for a redesign of the edge emitter to better match the device impedance to the impedance of the test system. This option program is anticipated to begin May 1, 1993.

- Approximately $5K remains from the baseline program. These funds will be used to complete documentation and prepare a final report of the baseline program.